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The effect of flocculants on the filtration of bagasse pulp pads

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Abstract

In this study the effect of flocculants on the filtration parameters of bagasse pulp was examined with surprising results. In the first experimental phase, a flocculant system was studied using a Dynamic Drainage Jar apparatus and the flocculants were found to be effective for improving the fibre retention of three different bagasse pulp slurries. In the second experimental phase pulp pads were formed using these flocculants and the steady-state permeability and compressibility parameters were measured.

The flocculant system which was effective for a pulp slurry was entirely ineffective in improving pulp pad permeability or compressibility during the second experimental phase for two of the bagasse pulp samples.

Introduction

Bagasse is the residual fibre after sugarcane has been harvested and crushed to obtain the juice that is rich in sugar. Despite having many similar properties, such as fibre length, hardwood chemical pulp is preferred to bagasse chemical pulp because it normally has better filtration properties. The presence of a very high quantity of short 'pith' fibres (length < 0.4 mm) is noted to detrimentally affect the production rate (1, 2). Using bagasse pulp rather than hardwood pulp typically reduces paper machine production rate by 25-30%. These 'pith' fibres constitute 30% to 40% of the bagasse. It has long been known that depithing of the bagasse is essential to make pulp of acceptable quality (e.g. refer to 3). If the filtration properties of bagasse pulp were more competitive then it might be considered more favourably by paper manufacturers. They would not have to reduce production rate by changing from a hardwood feedstock to a potentially cheaper bagasse based feedstock.

Two parameters affect the filtration properties of fibre beds; compressibility and permeability. In previous studies, a high permeability bagasse pulp was produced by heavily depithing the bagasse prior to pulping. The steady-state permeability and compressibility of pads made from this pulp was measured (4, 5). Under dynamic conditions, i.e. when the pad is compressed quickly, both permeability and compressibility vary over time. A model that combines the dynamic compressibility and permeability effects was developed to further understand the behaviour of bagasse pulp (4).

The objective of this study was to determine how flocculants affect the filtration properties of bagasse pulp pads.

In the first set of experiments, the effect of flocculants on a bagasse pulp *slurry* was assessed using a Dynamic Drainage Jar (i.e. a "Britt Jar"). For the remaining three experimental phases a thick saturated pad was first formed investigating the effect of flocculants. In the second set of experiments, the steady-state *pad* permeability was measured in a permeability cell. In the third set of experiments, pulp *pads* were very slowly dewatered by uniaxial compression in a compression cell under conditions that simulated steady-state compression behaviour. Finally pulp pads were compressed quickly under dynamic conditions of varying permeability and compressibility. A microscopy investigation into the fibre morphology was also conducted to obtain supplementary information and to confirm experimental observations.

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Three types of bagasse pulp were tested: a benchmark bagasse pulp which had been depithed to a similar extent to that normally performed industrially (i.e. 30%); and two highly depithed bagasse pulp samples. These two highly depithed bagasse pulp samples were found in a previous study to have far superior permeability properties compared to the benchmark bagasse pulp (5).

This paper proceeds by presenting the theory for the compression and permeability behaviour of pulp pads. The experimental setup and methodology for the two experimental phases are explained. The results are discussed including the possible mechanisms for the consolidation of bagasse pulp pads.

Compressibility and permeability theory for pulp pads

Pulp pad consolidation

Experimental investigations into the mechanisms of pulp pad consolidation usually involve either investigating the dewatering potential of a pulp slurry or compressing a very thick pulp pad. Both methods have strengths and weaknesses. The dewatering of a pulp slurry most closely resembles wet-end formation that occurs on a paper machine. With respect to bagasse pulp, which is extremely heavily laden with short fibres, this approach is particularly good for investigating how much of the short 'pith' fibre is retained and its impact on the dewatering potential. The quantity of pith fibres varies as the slurry dewaters. However, in order to understand the fundamental mechanics of how bagasse pulp compresses the quantity of short 'pith' fibre must be held constant over time. The steady-state conditions required for this study are most accurately and easily determined by compressing thick pulp pads.

The mechanisms of fibre realignment in pulp pads are well described by Jonsson and Jonsson (6):

1. Fibre collapse
2. Fibre bending
3. Breaking of fibres
4. Fibre realignment

The fundamental filtration parameters of a compressible material, i.e. the steady-state permeability and compressibility, can be measured either directly from steady-state experiments or implicitly calculated from dynamic experiments. The permeability and compressibility parameters from the steady-state experiments were previously validated using dynamic experiments (4). Conversely the steady-state filtration parameters can be calculated from dynamic experiments using either a slurry where a mat is formed, i.e. $c<c_g$ or a very thick saturated pulp pad $c>c_g$ (c_g is the pulp concentration gel point, the concentration at which saturated pulp transitions from being two distinct zones to one continuous zone). The equations describing these two scenarios for dynamic conditions are dealt with by Landman and co-workers (7).

Steady-state permeability theory

The theory of laminar flow through a homogeneous rigid porous media is based on Darcy's law:

$$\frac{Q}{A} = \frac{K\Delta P}{\mu\Delta L} \tag{1}$$

where Q is the volumetric flow rate through a bed of porous material with cross-section area A, ΔP is the frictional pressure drop across the length (ΔL) of the porous media bed, μ is the fluid viscosity which is customarily assumed to be constant and K is the specific hydrodynamic permeability of the porous material.

The permeability of a pulp mat, K, is determined experimentally from Darcy's Law. K is affected by the concentration of the pulp and also the structural arrangement of the mat. These factors are accounted for in the Kozeny-Carman model. The relationship is:

$$K(\phi) = \frac{1}{kS_v^2}\frac{(1-\phi)^3}{\phi^2} = \frac{1}{kS_v^2}\frac{(1-\alpha c)^3}{\alpha^2 c^2} \qquad (2)$$

where S_v is the specific surface area, and k is the Kozeny factor. The values for S_v and α which give the best fit for the permeability data can be easily calculated from simple experiments. S_v and α are determined from the slope and intercept of a plot of $(Kc^2)^{1/3}$ against c. S_v and α are the parameters used for comparative purposes in this study because they are independent of pulp concentration.

The Kozeny factor, k, is sometimes assumed to be constant, 5.55. This value is based on work by Fowler and Hertel (8).

$$k = 5.55 \qquad (3)$$

A common criticism of this approach is that k varies with solidity as discussed by Davies (9). This was validated for bagasse pulp by Rainey and coworkers (4). This effect was considered for this study but the form of k had no effect on the outcome of this study. Consequently, a simple constant k was employed.

Steady-state compressibility theory

In this study the compressibility equipment was set up so that the pulp could be loaded into a cell and compressed with a permeable top platen which expresses water.

The hydraulic pressure at the top surface of the pulp mat is negligible so the force on the fibres equals the force exerted on the platen.

The pressure on the solid phase is P_s at the platen. The steady-state compression model used in this study is a simple power law model, $P_s = M\ c^{N}$, where c is the pulp concentration and M and N are experimental constants.

In this study quasi steady state behaviour is achieved by compressing the pulp mat over a very long time period. During steady state compression, the permeability effects are insignificant. The hydraulic load is negligible compared to the mechanical load. The graph of $\log(P_s)$ against $\log(c)$ is approximately linear. Values of M and N are obtained from the slope and intercept of the linear approximation.

Experimental procedure

Firstly, the bagasse pulp was prepared. A suitable shear stable flocculants system was optimised using a DDJ. Finally, the flocculants were used whilst making pulp pads. The steady-state permeability and compressibility experiments and dynamic filtration experiments were performed both with and without flocculants. A microscopy study was undertaken to determine the morphology of the fibres.

Bagasse pulp preparation

Bagasse was collected in northern Australia, from CSR Invicta's milling train and immediately cooled and carefully washed so that the sugar was removed. This was performed in a manner to ensure that no pith was lost. The bagasse was then stored in a coldroom. This treatment method minimised the degradation of bagasse that may have otherwise affected laboratory results. Poor bagasse storage methods can adversely affect the repeatability of laboratory testing. Bagasse degrades very quickly if it is not carefully prepared.

Three pulp samples were produced. In industrial operations, bagasse is normally moist and wet-depithed prior to pulping. This treatment typically removes around 30% of the fine pith fibre. A benchmark pulp sample was produced from bagasse that had only had 30% of the short pith fibre removed. For the other two pulp samples, the bagasse was manually sieved for 3 min using a 4 mm screen. The total amount of pith removed was higher than normally used by industry in order to achieve good filtration properties. Two fractions were generated from the highly depithed bagasse. A 'coarse' bagasse fraction was retained on a 12 mm screen when handfuls of bagasse were manually sieved for 3 minutes. A 'medium' bagasse fraction passed through the 12 mm screen but was retained on the 4 mm screen.

The depithed bagasse pulp samples (80 g - 100 g) were produced in a 6×1.5 L cell digester at the Australian Pulp and Paper Institute (APPI, Melbourne). Fifty litres of soda anthraquinone (AQ) cooking liquor was recirculated through six cells containing the bagasse. The pulping conditions were: 0.4 M sodium hydroxide (approx. 13.8% Na_2O on oven dry fibre), 0.1% AQ, (on oven dry fibre) at 145°C for 30 min. The pulp was screened through a 200 μm Packer screen and the pulp kappa number was 20. The pulp was never allowed to dry.

Experiments using the Dynamic Drainage Jar

For the experimental program, it was first necessary to establish a suitable flocculant system for a bagasse pulp slurry. This was performed in a DDJ. The DDJ is a useful tool for determining the shear stability of a flocculant system because the shear can be easily varied by adjusting the stirrer speed and the retention of fines is determined. A good flocculant system will be effective under high shear conditions and this is quantified by high retention of short pith material.

Pulp flocculants were obtained from Ciba Specialty Chemicals. Ciba recommended Percol 182, a high molecular weight cationic polyacrylamide (CPAM) in conjunction with Hydracol ONZ, a modified bentonite microparticle, based on their own experience with mechanical pulp which also has a high quantity of fine fibre. This study only investigated these two additives.

The efficacy of the flocculants was tested using a DDJ for their suitability in bagasse paper manufacture. Their efficacy was quantified using fines retention in this part of the study. CPAM was tested in the range 0.01% to 0.5% (on dry fibre) and the bentonite was tested from 0% to 1.6% (on dry fibre). The Tappi test method was followed for measuring the retention of fines (10). A standard 76 μm screen was used. In the procedure, the stirrer speed is increased over a series of experiments and the fines retention is calculated each time.

All data obtained using the DDJ was collected in duplicate.

The effect of flocculants on pulp pad permeability and compressibility

<u>Steady-state permeability testing of bagasse pulp pads</u>

In order to obtain the steady-state permeability of pulp pads a simple 'permeability cell' was used. The cell is a clear Perspex tube that can be filled with pulp and attached to a constant head tank. A steady flow of water through the cell can be achieved. The pressure drop across the pulp pad was measured using two manometers.

Thirty grams of equivalent dry pulp and 3 L of distilled water were added to a disintegrator to make a pulp slurry of 0.9 % consistency. For experiments involving flocculants, 0.05% CPAM (on dry fibre) was added to the slurry, stirred slowly with a spatula for 30 s, followed by the addition of 0.06% of bentonite (on dry fibre). These ratios were determined from the experiments with the Dynamic Drainage Jar. Two litres of this slurry was then slowly poured into the permeability cell to form a saturated mat. The slurry was vigorously agitated as it was added to the cell to ensure uniform layering of the pulp fibres in the cell.

The cell was then connected by a constant head tank to a water supply (see Figure 1). Flow was slowly increased until steady-state conditions were obtained. The pressure drop across a fixed height of pulp mat was measured by manometers and the flowrate of water was measured with a measuring cylinder and stopwatch.

The pressure drop and flow rate data were used to determine Darcy's permeability, K, and consequently the specific surface area, S_v, and the swelling factor, α, over a range of pulp concentration.

This method was used to measure the permeability properties of bagasse pulp without flocculants in a previous study (5).

Quasi steady-state compressibility testing

A simple compression cell was fabricated (see Figure 2 and Figure 3) and mounted to an Instron 5500R. For this study the load applied did not exceed 5 kN. The cell was 100 mm in height, the platen was 10 mm thick, resulting in a total possible working height of 90 mm. The platen was fitted with a shamband and Teflon ring to prevent water flowing around the platen, and the platen was drilled with thirty 6 mm holes for the water to evacuate.

The method used for making the pulp pads for the compressibility cell was the same as for the permeability cell. Pulp samples were disintegrated to 0.9% consistency. The barrel of the compressibility cell was removed from the base and suspended on a screen of 100 mesh. For experiments involving flocculants, CPAM and bentonite were added to the slurry. The disintegrated pulp was added to the barrel of the compressibility cell and the bulk of the water was allowed to drain through the mesh. Once the desired height of pulp in the barrel was reached, the barrel, the supporting screen and the loaded pulp could be transferred to the base and bolted in. The pulp mat remained saturated during the transfer; this was easy to achieve. The platen of the compressibility cell was then connected to the Instron, ready to commence the compression experiment (see Figure 3).

For all of the compressibility tests, the platen finished compressing the pulp mat at 15 mm above the base of the cell. The platen was lowered very slowly over 300 min at a constant rate of 0.25 mm/min (that is, 75 mm over 300 min) in order to achieve quasi steady-state conditions. The pulp samples were compressed several times to obtain average values of M and N (excellent repeatability was possible). The Instron load and time were logged. The load on the platen was recorded by the Instron and converted to pressure. The frictional resistance between the Teflon seal and the barrel was taken into account, which was typically equivalent to only 2.5 – 4.5 kPa.

Dynamic compressibility testing

Finally, a pulp pad was loaded into the compression cell and the compression speed was increased by 100 times in most instances to 25 mm/min (that is 75 mm over 3 min).

For the dynamic compressibility testing, the compression cell was loaded to 75 mm in depth, leaving 15 mm clearance to the platen, and compressed to 15 mm. The lower initial height of the pad is required for the dynamic testing because the calculated values of the compressibility constants are valid over the limited range of pressures used in the quasi steady state testing.

Microscopy investigation

The morphology of the pulp fibres was analysed by Scion, New Zealand, using a confocal laser microscope. This investigation was performed to gain insight into the shape of both bagasse pulp fibres and eucalypt pulp fibres and how they might behave during pad compression.

The ‘coarse’ and ‘medium’ bagasse pulp samples were analysed after being compressed. Due to budgetary constraints it was not possible to analyse the benchmark bagasse pulp. 500 fibres from each pulp sample were chemically dehydrated by solvent exchange through a graded series of water/acetone solutions. Fibres were then mounted in a Spurr’s resin and the resin was allowed to cure before the surface was sectioned and polished for image analysis. The images were analysed using Scion’s image analysis software. A small quantity of chipped and broken fibres as well as contaminants were removed during the image analysis.

Figure 4 shows a typical fibre section with the fibre width and thickness dimensions determined in the image analysis.

Apart from the measurements shown in Figure 4, i.e. fibre width, fibre thickness, fibre area and fibre perimeter, the collapse ratio was also calculated. The collapse ratio is defined as the fibre width divided by the fibre thickness. These measurements were compiled for each sample of 500 fibre sections. The distributions of these parameters were collected.

Results

Results of the experiments using pulp slurry

The effectiveness of CPAM and bentonite was measured on the benchmark bagasse pulp. An addition rate of 0.05% CPAM, which is the mid-point recommended by the supplier for a mechanical pulp heavily laden with fine fibre was used as a basis for further experiments with flocculants.

The optimum addition rate of bentonite to a pulp slurry containing 0.1% fibre and 0.05% CPAM was around 0.06%. It was found that for higher addition rates of bentonite the retention actually reduced; a high level of bentonite was observed in the filtrate. Above this addition level, bentonite is in excess and not attached to the fibre flocs.

The combination of 0.05% CPAM + 0.06% bentonite chemicals improved the retention of all types of bagasse pulp under all shear conditions. These addition rates of CPAM and bentonite were then applied to the other bagasse pulp samples.

In these experiments, the fines material accounted for 10.6%-11.1% of the pulp (a pulp without any pith removed, i.e. a 'whole' bagasse pulp, was found to contain about 20% fines). It is noted that the fines retention affects the process economics. The fines retention was generally around 60% at high turbulence levels (1500 rpm) and rose to between 80% and 100% when CPAM and bentonite was used.

The effects of flocculants on the pulp pad permeability and compressibility parameters

It was found that flocculants affected the S_v, M and N of only the benchmark bagasse pulp. The 'coarse' and 'medium' bagasse pulp could not be shown, statistically speaking, to be affected by flocculants.

<u>The effect of flocculants on bagasse pulp permeability parameters</u>

The steady-state permeability properties of each bagasse pulp was conducted firstly without flocculants and then with CPAM and bentonite. Figure 5 shows examples of the data sets for a 'coarse' and 'medium' bagasse pulp respectively. As can be observed from the figures, there was not found to be a statistically significant difference in the slope or intercept of these plots and consequently no difference in S_v or α. This was confirmed using Student's t-test with a 95% confidence interval, using the pooled estimate of standard deviation.

The effect of additives was significant for the benchmark bagasse pulp, see Figure 6. The benchmark bagasse pulp had higher permeability when flocculants were used. This was confirmed using Student's t-test at a 95% confidence interval. For comparative purposes, the permeability was compared to a eucalypt pulp and a bagasse pulp which had not been depithed (both pads were prepared without additives). Even with flocculants added, the benchmark '30% depithed' bagasse pulp had lower permeability than the eucalypt but the depithed bagasse pulp was far better than the undepithed ('whole') bagasse pulp.

The results for S_v and α are shown in Table 1. The flocculants had a strong effect on the benchmark bagasse pulp, greatly reducing its S_v but not on the 'coarse' or 'medium' bagasse pulp. There was not found to be any statistically significant difference in α for *any* bagasse pulp sample using a 95% confidence interval.

<u>Effect of flocculants on bagasse pulp compressibility parameters</u>

The steady-state compressibility of bagasse pulp was measured both with and without using the CPAM/bentonite system. Figure 7 shows typical results for a 'coarse' and 'medium' bagasse pulp respectively. In both figures, the data is shown prior to the addition of flocculants and after the addition of flocculants. There was no difference in the steady-state compression factors M and N.

The effect of flocculants is observed on the steady state compressibility of the benchmark '30% depithed' bagasse pulp (Figure 8). This mirrors the observation that flocculants only affect the permeability parameters of a 'depithed' bagasse pulp.

Typical results for the steady-state compressibility test are shown in Table 2. These results were duplicated using pulp samples from independent cooks. The only statistically significant result is that the flocculants system affected the benchmark bagasse pulp compressibility parameters by increasing both M and N.

The effect of flocculants on bagasse pulp's dynamic filtration behaviour

The pulp pads were again compressed in the compression cell to look at the effect of flocculants but this time under dynamic conditions. The results for 'coarse' pulp, 'medium' pulp and the benchmark '30% depithed' pulp are shown in Figure 9. These results were reproduced with independently cooked pulp samples.

The 'coarse' bagasse pulp required by far the least load in order to compress the pulp pad and the benchmark bagasse pulp ('30% depithed') required a far higher load. However, the flocculants had a negligible influence on reducing the required load pressure for a 'coarse' bagasse pulp (around 5%) compared to the benchmark bagasse pulp (around 40%). The 'medium' bagasse pulp required an interim load pressure but the flocculants were only modestly effective; the influence of flocculants on the dynamic load behaviour is debatable.

Microscopic analysis

Confocal laser microscope and image analyses were used to obtain additional information about fibre morphology. Over 500 fibre sections were analysed for both pulp samples, 'coarse' and 'medium' bagasse pulp. Some of the key results of the microscopy investigation are reported in Table 3.

The wall thickness for the bagasse pulp was around 5 μm and the fibre width was around 20 μm. The collapse ratio for the 'coarse' bagasse pulp was 1.48 and it was 1.66 for the 'medium' bagasse pulp was substantially lower than for the 'medium' bagasse pulp. These collapse ratios and the other morphological data indicates that fibre collapse is not a primary mechanism for pulp pad consolidation. Furthermore, individual 'collapsed' fibres were not observed in this study. In fact, it will be shown from the experimental evidence that the longer fibres are quite stiff compared to wood species (see Discussion).

Discussion

In the experiments involving the compression cell, the 'coarse' and 'medium' bagasse pulp required far less load in order to compress. Flocculants did not affect the steady-state permeability or compressibility constants of these two pulp samples but had a dramatic affect on the benchmark bagasse pulp.

The possible mechanisms for consolidation of compressible fibrous media are (i) fibre collapse (ii) bending of fibres (iii) breaking of fibres and (iv) fibre realignment. It is interesting at this point to gain insight into which mechanism is altered for the conditions tested in this study.

To begin, the Australian bagasse fibres are very rigid and significant irreversible plastic deformation, i.e. fibre collapse, was not observed in the microscopy study. This result is tentative as the number of samples measured was relatively small in comparison to the number of contact points between fibres in the collapsing network. We discount this mechanism as well as the fibre breakage/external fibrillation mechanism as the specific surface remained essentially unchanged from test to test.

With regards to the last two mechanisms, fibre bending and fibre realignment, we anticipate that both these mechanisms play a significant role during pad densification. We do however believe that the effect of the chemical additions aided pad densification through both a reduction in inter-fibre columbic friction or through changes in the fluid rheology. It is well known that the additives used in this study have a shear thinning behaviour. This latter phenomenon may result in the ease by which water is removed from the fibre wall during compression. These speculations will need to be substantiated by further work.

Conclusions

The effectiveness of a microparticle flocculent system system was investigated using a DDJ. It was found that addition of 0.05% CPAM and 0.06% modified bentonite improved the retention of bagasse pulp fines over a wide range of shear using a DDJ.

For processing initially networked fibre pads under dynamic conditions, a heavily depithed 'coarse' bagasse pulp was by far the most easily dewatered bagasse pulp and the filtration properties were mostly unaffected by flocculants.

A microscopy analysis confirmed the experimental observation that the bagasse pulp fibres were not collapsing nor breaking. The permeability and compressibility experiments were highly repeatable. It is believed that both fibre bending and realignment play important roles in bagasse pulp pad compression.

In steady-state permeability and compressibility experiments, the addition of flocculants could only be determined to improve S_v for one type of pulp; the '30% depithed' pulp. However, dynamic filtration experiments showed that there was also an improvement for the 'medium' bagasse pulp.

Acknowledgements

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Nomenclature

A is the cross sectional area of a porous bed for use with Darcy's Law, cm^2
c is pulp concentration, g/cm^3
c_g is pulp gel point concentration, g/cm^3
K is Darcy's permeability constant, cm^2
k is the Kozeny factor, -
ΔL is the height of a bed of porous material for use with Darcy's Law, cm
M is a compressibility constant, kPa, used in the expression $P_s=Mc^N$
N is a compressibility constant, -, used in the expression $P_s=Mc^N$
ΔP is the pressure drop across a bed of porous material for use with Darcy's Law, mPa
Q is the flowrate through a porous material for use with Darcy's Law, cm^3/s
S_v is the specific surface area of pulp fibre (cm^2/cm^3)
x is the distance from the top platen, cm

Greek letters
α is the pulp swelling factor, cm^3/g
μ is the liquid viscosity, mPa.s

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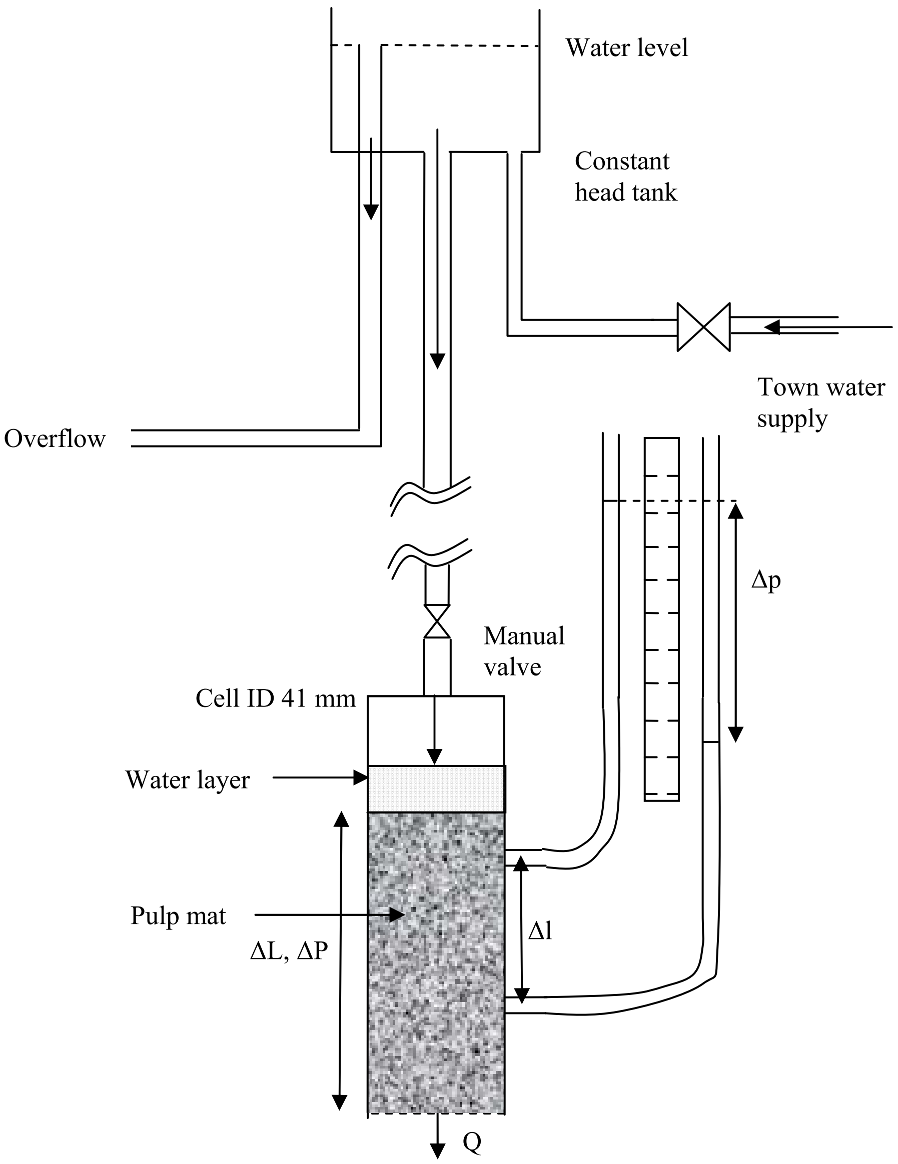


Figure 1 **Schematic diagram of the apparatus used for permeability measurements (5)**

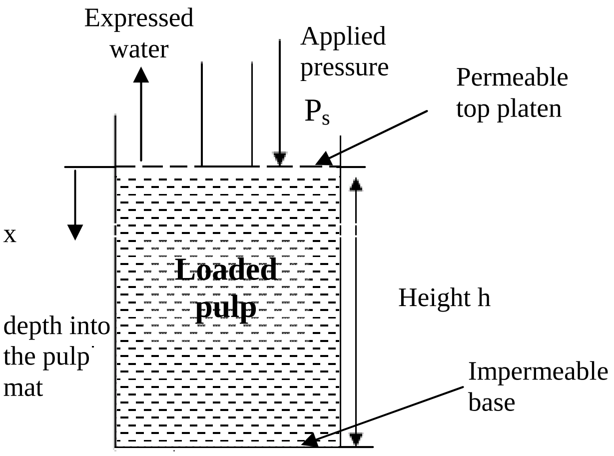
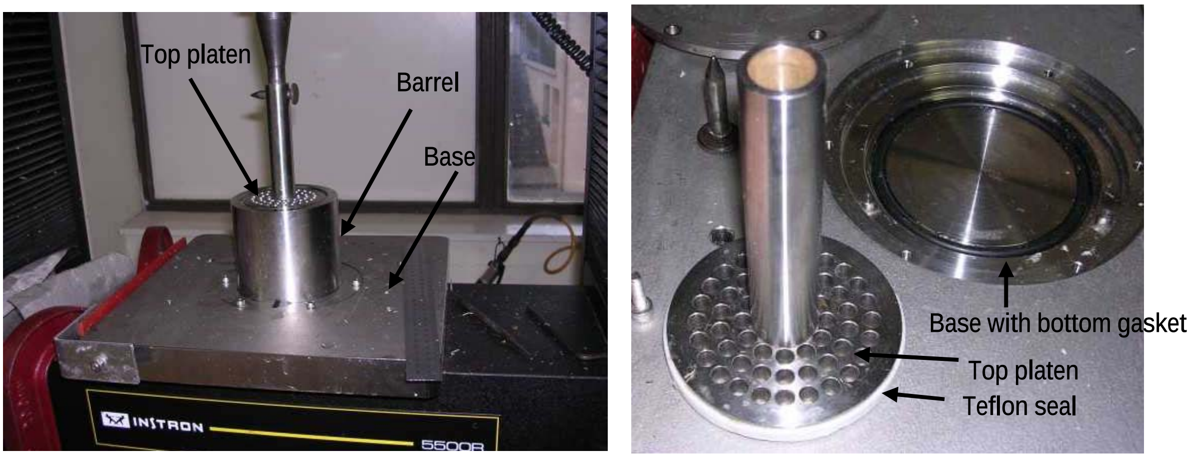


Figure 2 **Sketch of the compressibility cell**



(a) (b)

Figure 3 **Photographs of (a) the loaded compressibility cell with the barrel fixed onto the base and (b) the top platen and the base of the cell when the cell is dismantled (4)**

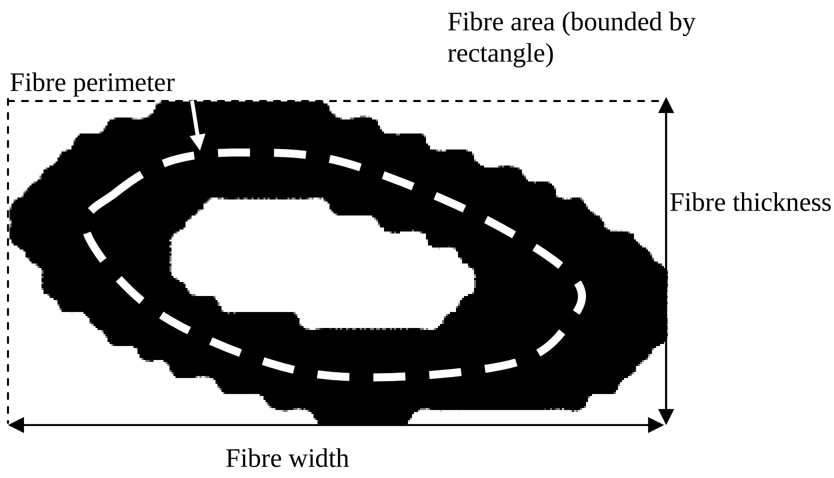
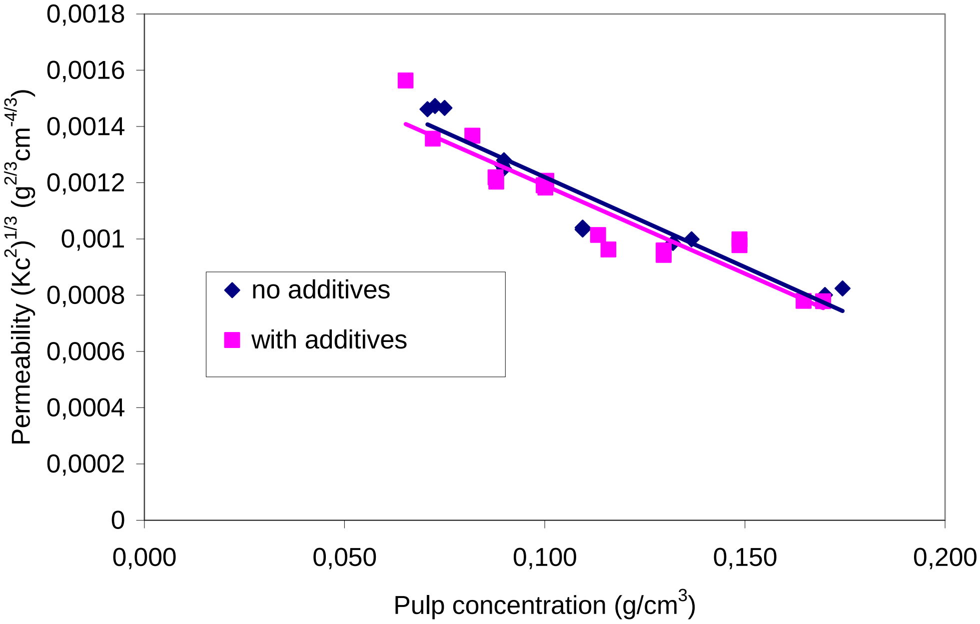


Figure 4 **An image of a bagasse fibre cross section showing fibre width and thickness for the microscopy investigation.**



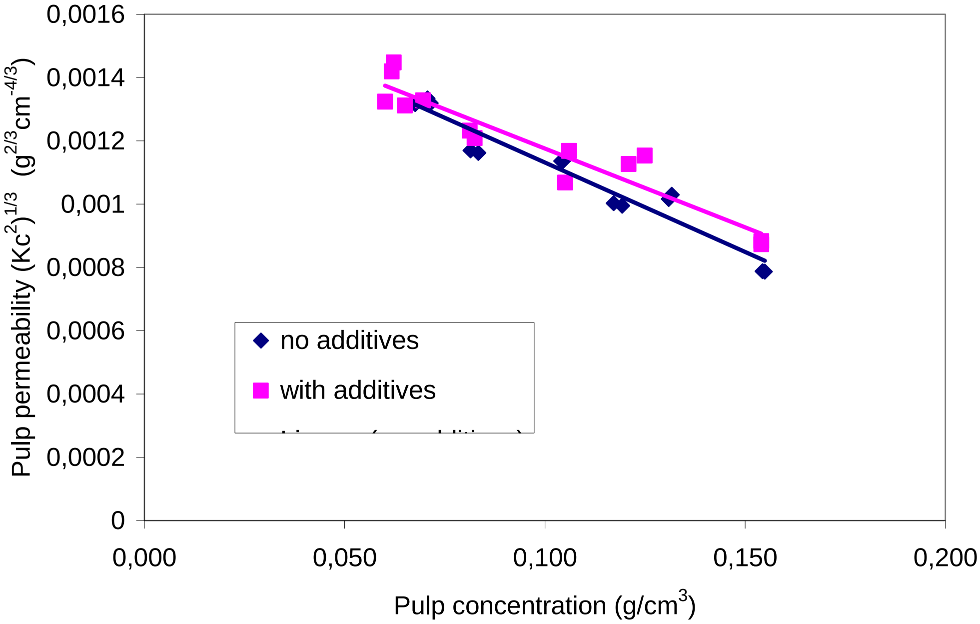


Figure 5 **The effect of flocculants on the permeability of a 'coarse' bagasse pulp (top graph) and 'medium' bagasse pulp (bottom graph).**

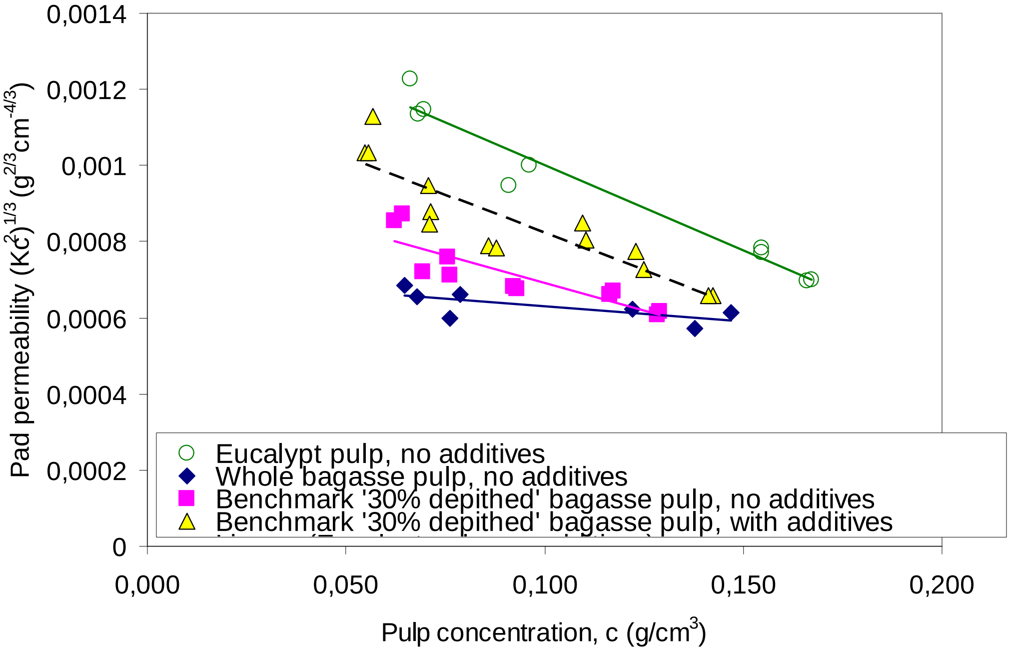


Figure 6 **The effect of flocculants on the permeability of the benchmark '30% depithed' bagasse pulp in comparison to a eucalypt pulp and a bagasse pulp which had not been depithed.**

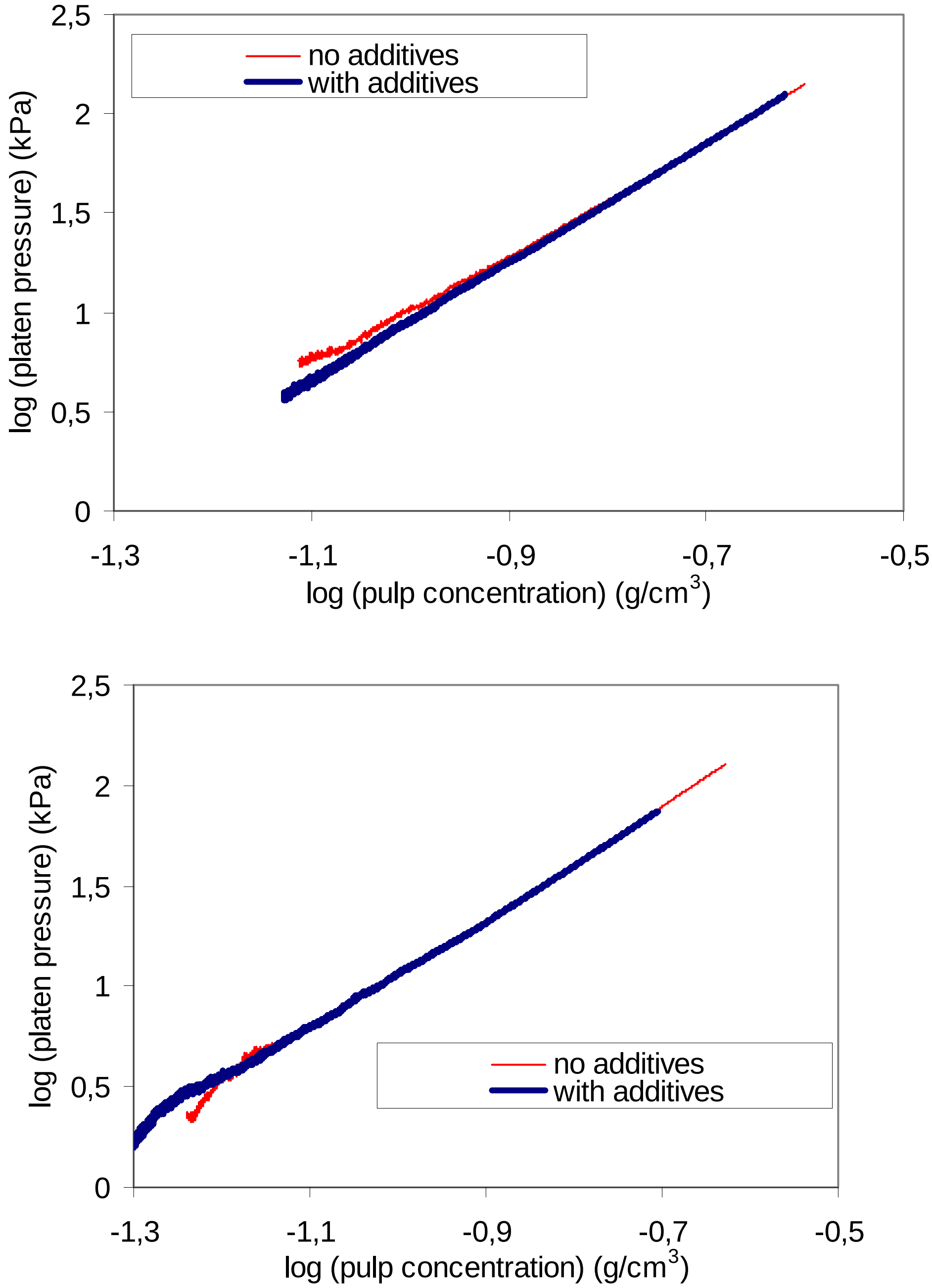


Figure 7 **The effect of flocculants on the steady-state compression of 'coarse' and 'medium' bagasse pulp.**

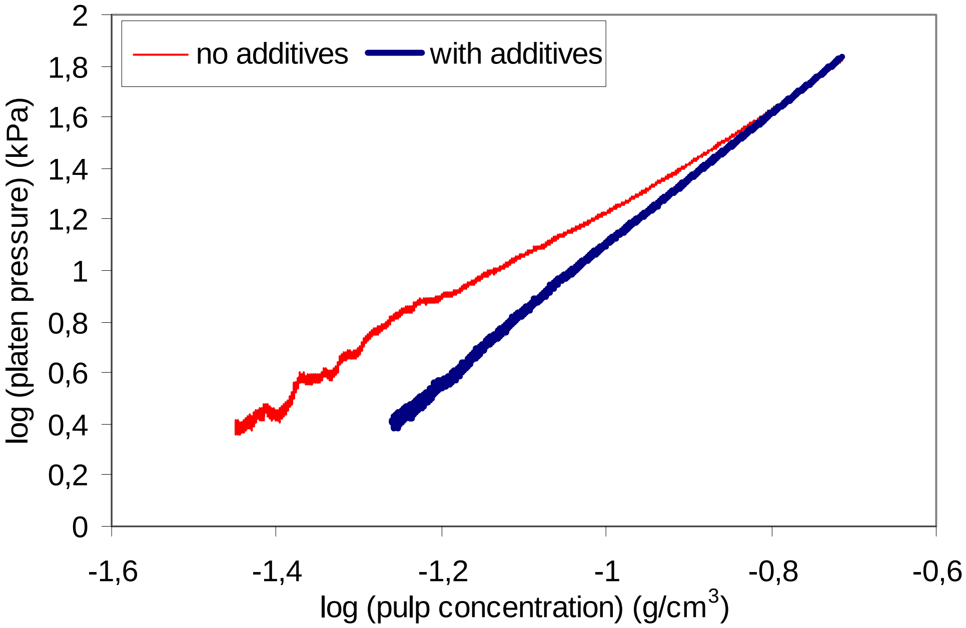


Figure 8 **The effect of flocculants on the steady-state compression of 'depithed' bagasse pulp.**

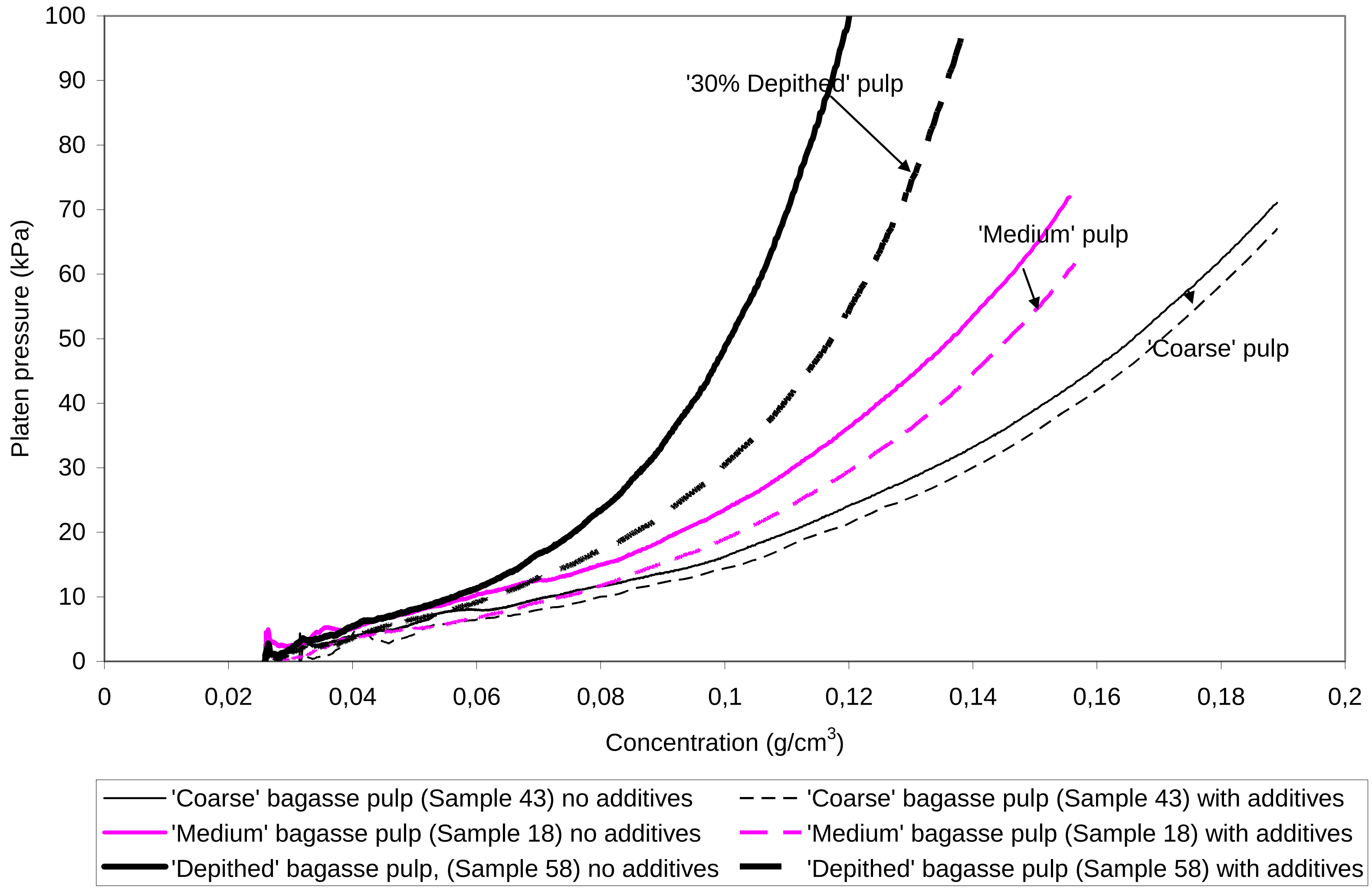


Figure 9 **The effect of flocculants on the dynamic filtration of 'depithed', 'coarse' and 'medium' bagasse pulp.**

Table 1 **Effect of additives on the permeability parameters S_v and a.**

Parameter	Bagasse pulp type	No additives	With additives
a (-)	Coarse	3.44	3.45
$\sigma_{PESD,\,\alpha}$=0.216	Medium	3.33	2.98
	Benchmark 30% depithed	2.97	3.26
S_v (cm^{-1})	Coarse	1540	1580
$\sigma_{PESD,\,Sv}$=211 cm^{-1}	Medium	1820	2080
	Benchmark 30% depithed	4640	3060

Table 2 **Typical effect of flocculants on bagasse pulp compressibility parameters.**

Parameter	Bagasse pulp type	No additives	With additives
Log M (kPa)	Coarse	3.77	3.93
$\sigma_{PESD, logM}$=0.15	Medium	3.79	3.79
	Benchmark 30% depithed	3.14	3.74
N, -	Coarse	2.76	2.98
$\sigma_{PESD, N}$=0.12	Medium	2.73	2.73
	Benchmark 30% depithed	1.89	2.65

Table 3 **Results of microscopy study using a confocal laser microscope and image analysis.**

	Bagasse pulp derived from the coarse bagasse fraction	**Bagasse pulp derived from the medium bagasse fraction**
Fibre width (μm)	20.2	20.7
Fibre thickness (μm)	13.9	12.7
Wall thickness (μm)	5.13	4.72
Fibre area (μm^2)	214	200
Fibre perimeter (μm)	68.5	67.6
Wall area (μm^2)	186	169
Lumen area (μm^2)	31.0	27.9
Collapse ratio (-)	1.48	1.66
Minimum wall thickness (μm)	3.46	3.18
Maximum wall thickness (μm)	7.03	6.70